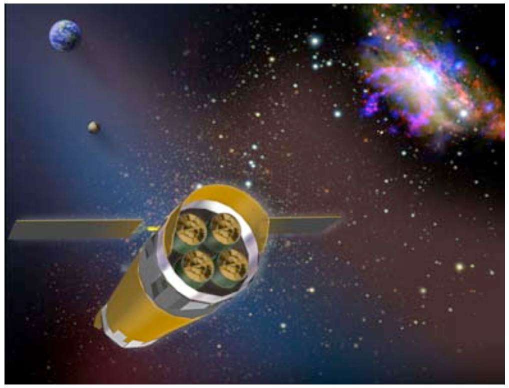
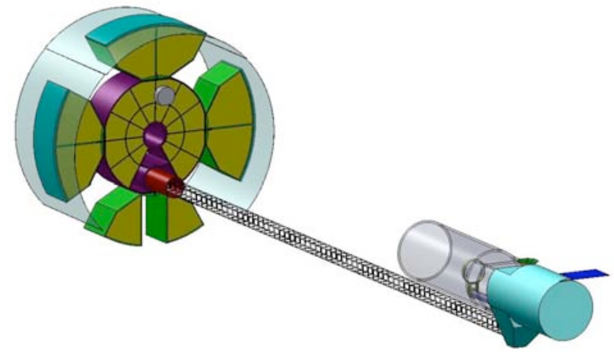
Ares V Astronomy Workshop

Ames, 26-27 April 2008





Generation-X: A Mission Enabled by Ares V

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Outline

- Science Drivers
- Vision Mission Concepts
- Astrophysics Strategic Mission Concept
- Ares V Considerations
- Technology Development

Gen-X Astrophysics Strategic Mission Concept Study (AMCS) Proposal

- Gen-X: large area, high angular resolution X-ray telescope to study the early universe, evolution of BH, galaxies and elements, and extreme physics
- Follows Chandra, XMM-Newton and Con-X
- Launch 2025-2035
- Study will build on the successful 2004-05 Vision Mission study
- Ares V capability results in simplified and more cost-effective baseline mission concept
- Key Study product is a detailed technology development road map

Generation-X AMCS Team

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and collaborators

67 People, 21 Institutions
5 Industry Partners
2 NASA Centers

Generation-X Science Drivers

- EARLY UNIVERSE: The first black holes, stars and galaxies
  - X-rays penetrate haze of high z IGM, and gas and dust around objects
  - Provide a channel to z>6 and the Epoch Of Reionization
- EVOLUTION: of black holes, galaxies and the elements they produce vs cosmic time
  - X-ray observations trace baryon abundances and dark matter since much baryonic matter in form of hot gas (elliptical halos, clusters)
- PHYSICS: Probe the behaviour of matter in extreme environments
  - Density, gravity, magnetic field, kinetic energy
- Science drivers traced to observations to mission parameters and implementation

Science Drivers → Key Mission Parameters → Mission Implementation

Gen-X Mission Parameters Derived from Science Objectives

Parameter	Baseline
Effective Area (@1 keV)	50 m^2
Angular Resolution	0.1" HPD
Energy Resolution (@1 keV)	E/dE=3000
Background (0.5 – 2.0 keV)	0.004 cts/ks/$arcsec^2$
Energy Range	0.1 – 10 keV
Field of View	5 arcmin radius
Time Resolution	50 μs
Count Rate Limit	100 cts/sec/pix
Sky Availability	90%
Calibration	3% absolute
Launch Vehicle and Orbit	Ares V to Sun-Earth L2
Launch Date	2025-2035

Detecting the First Black Holes

- First epoch of energy injection at z~10-20 (0.2-0.5 Gyr) - WMAP
- Fast burning massive stars yield SN and first black holes
- Must grow at Eddington limit to reach observed quasar masses
- Fiducial numbers for Gen-X:

Black Hole Mass	1000 solar masses
Eddington Limit	6.5×10^{40} erg/s
Redshift	15
Flux	3×10^{-20} erg/cm^2/s
Effective Area	50 m^2
Angular Resolution	0.1"
Count rate	5×10^{-6} cts/sec
Exposure time	1×10^{6} s (~5 counts in 1 Ms)
Background rate	0.01 cts/ks/arcsec^2

- Drives 50 m^2 Effective Area and 0.1" Angular Resolution

Merging Black Holes and AGNs

- Merging black holes give insight into merger tree vs. redshift
- X-rays can see accreting black holes even for A_V=100
- Gen-X: 160 ks, z=1, can detect and resolve a binary AGN 2kpc apart.

- 0.1" resolution corresponds to physical scales of:

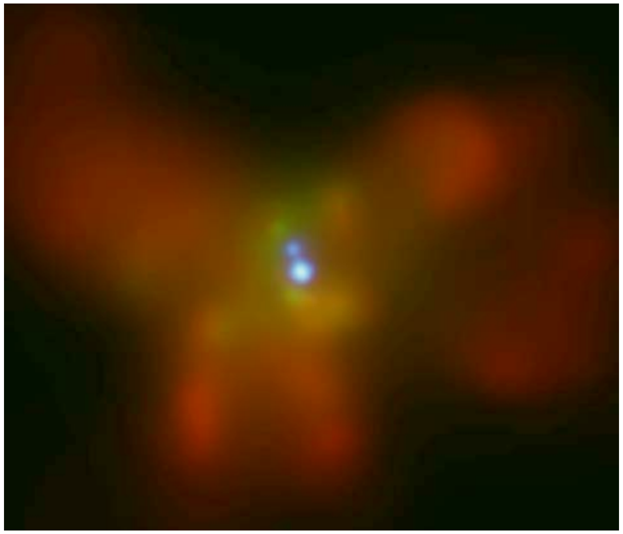
  0.8 kpc at z=3

  0.6 kpc at z=6

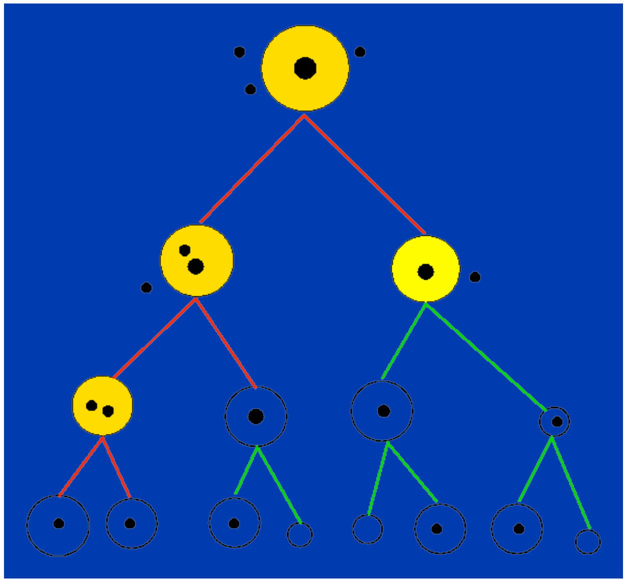
  0.3 kpc at z=15
- Hundreds of binary BH systems observable with separation of ~1 kpc

- Drives EA=50 m^2, Ang. Res=0.1", E/ΔE=10^3-10^4

Chandra image of NGC6240: two AGNs in a merger, ~1 kpc separation

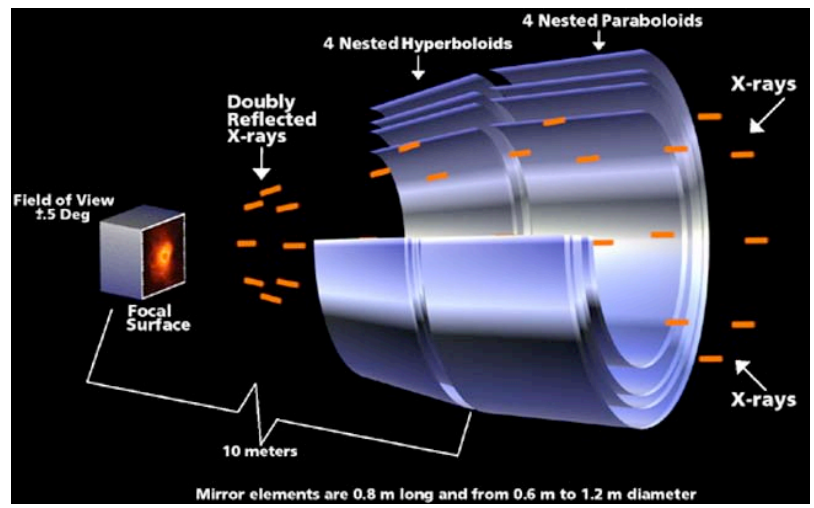


Schematic Black Hole Merger Tree



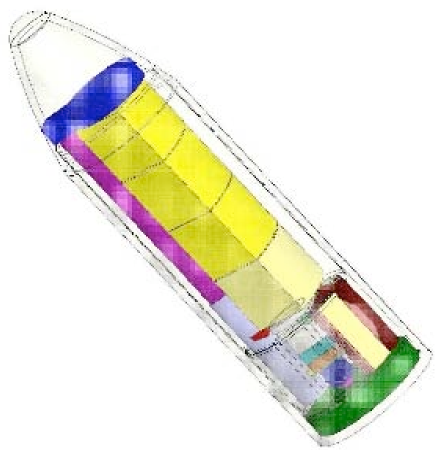
Design Considerations

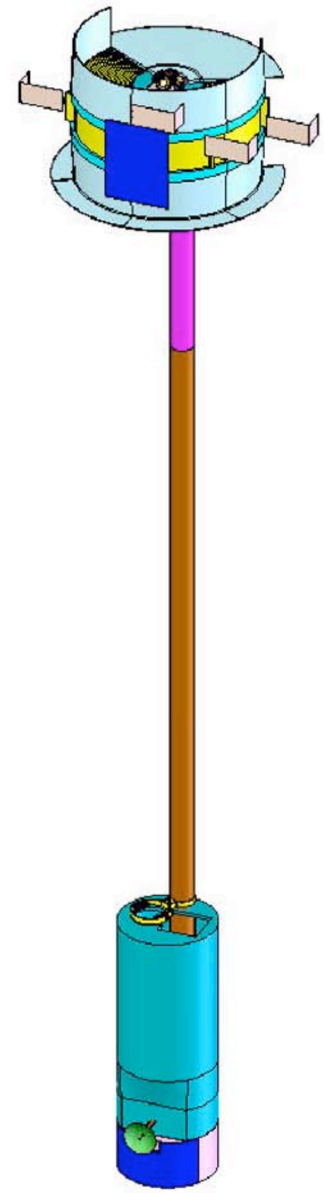
- Wolter Type I nested grazing incidence optics
- For 50 m^2 Effective Area need ~10^4 m^2 of glass area
- Very thin mirrors ~0.1-0.2 mm to meet launch mass requirements
- 50 m^2 EA implies ~12 m diameter mirrors so either multiple launches and assembly, multiple satellites, or single heavy lift
- Mirror diameter and grazing angle of 0.5-1 deg. to meet energy range 0.1-10 keV; yields focal length of 50-150 m
- Energy range, FOV, time resolution, non-X-ray background drive science instruments:
  - Reflection grating spectrometer (RGS)
  - Micro-calorimeter array (XRS)
  - Active Pixel imager (Wide Field Imager - WFI)



Original Vision Mission Concept (Delta 4-H)

- 6 identical telescopes
  - 16 m^2 effective area at 1 keV
  - 8 m diameter
  - 50 m focal length
  - Figure and alignments adjusted on orbit
  - Detectors attached to deployable boom
- 6 separate ELV launches (e.g., Delta 4H)
  - Telescope carried as 6 segments to fit in fairing
  - Telescope segments deployed automatically
  - Sun-earth L2 orbit
- Detectors
  - Reflection grating spectrometer
  - Micro-calorimeter array
  - Active pixel imager

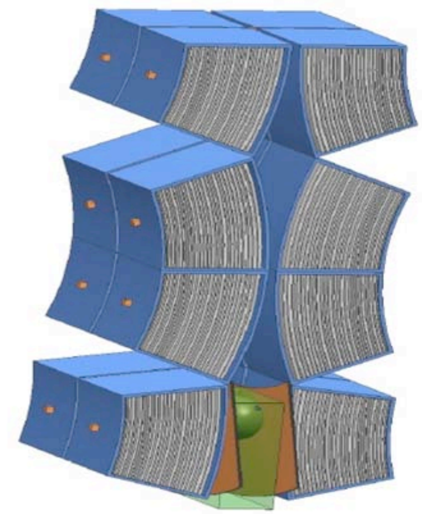


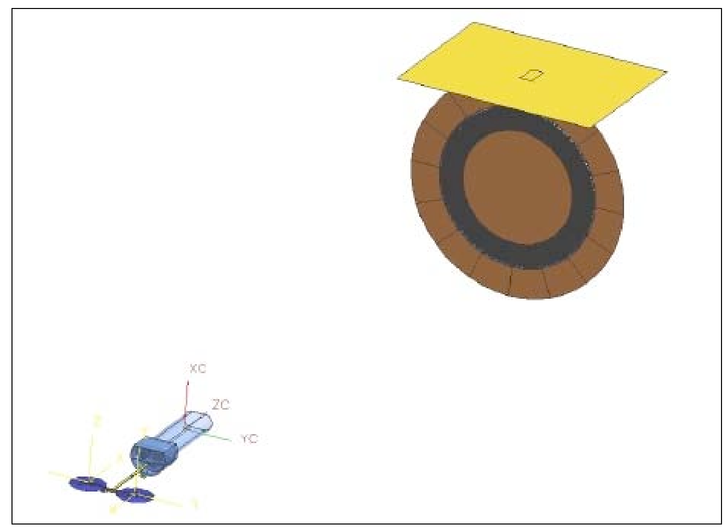


Alternate Vision Mission Concept: Single Mirror

- Single telescope Formation Flying
  - 20 m diameter
  - 125 m focal length
  - Figure and alignments adjusted on orbit
  - Detectors housed in separate spacecraft: formation flying
- 5 separate ELV launches
  - 16 segment telescope launched as 4 sets of 4 segments each
  - Telescope deployed autonomously
  - Science Instrument spacecraft launched separately
  - Sun-Earth L-2 Orbit
- Identical Science Instruments

- Preliminary Technology Development Roadmap developed as part of Study



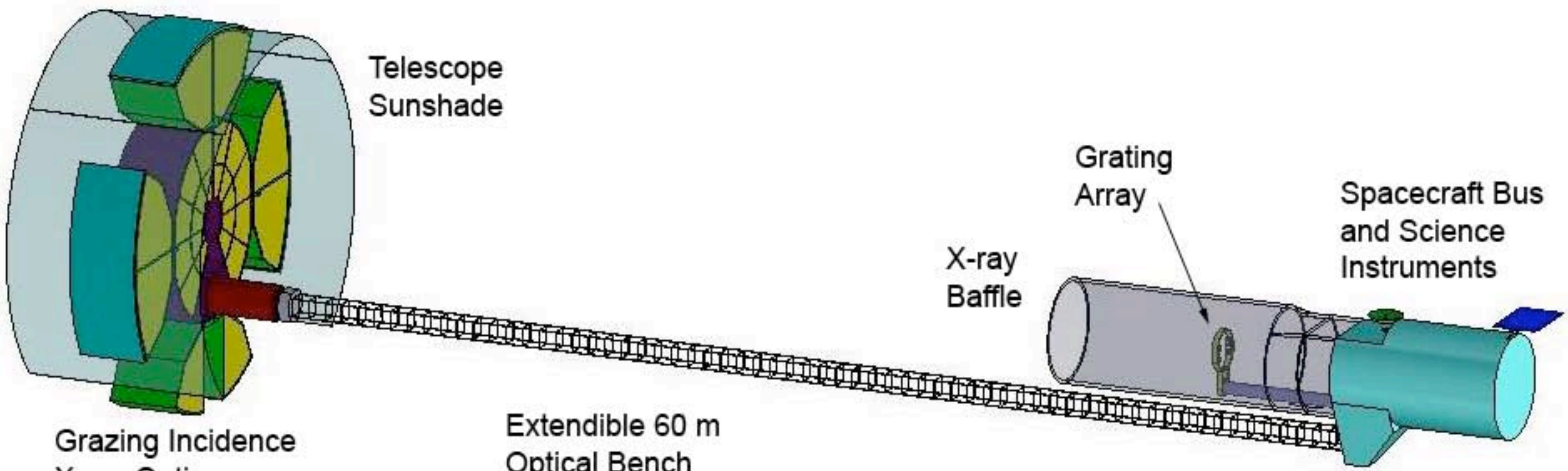


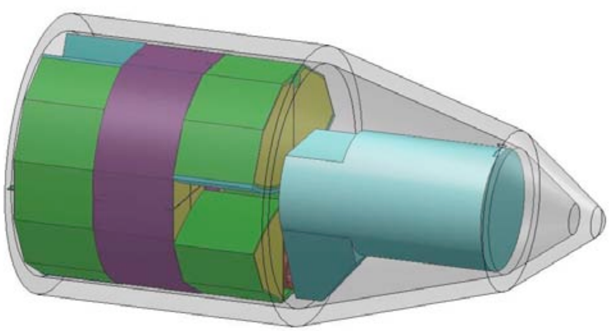
Gen-X Concept Study Baseline: uses Ares V

- Ares V enables simplified & more cost-effective mission concept
- Single spacecraft
  - 16 m-diameter partially filled deployable optic, ~50 m^2 effective area
  - Piezo-electric control of optic figure on-orbit to achieve ~0.1" angular resolution
  - 60 m focal length with extendable optical bench
  - Mirror folds to fit within 10m fairing dynamic envelope

- Deliver Gen-X directly to Sun-Earth L2
- Spacecraft mass estimate of 22 Metric Ton (MT) well within Ares V 60 MT capability to L2

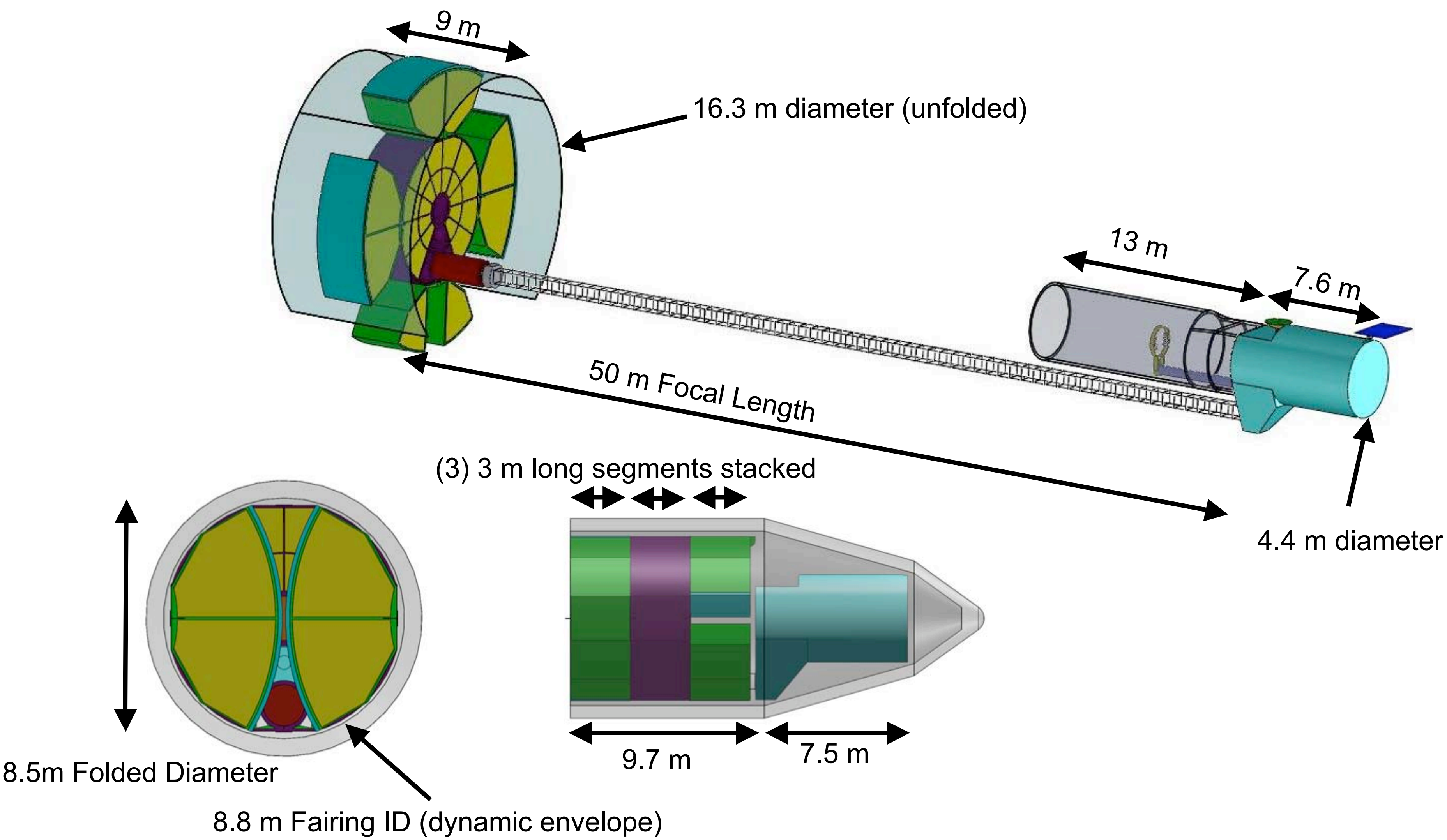
Reference Spacecraft Configuration





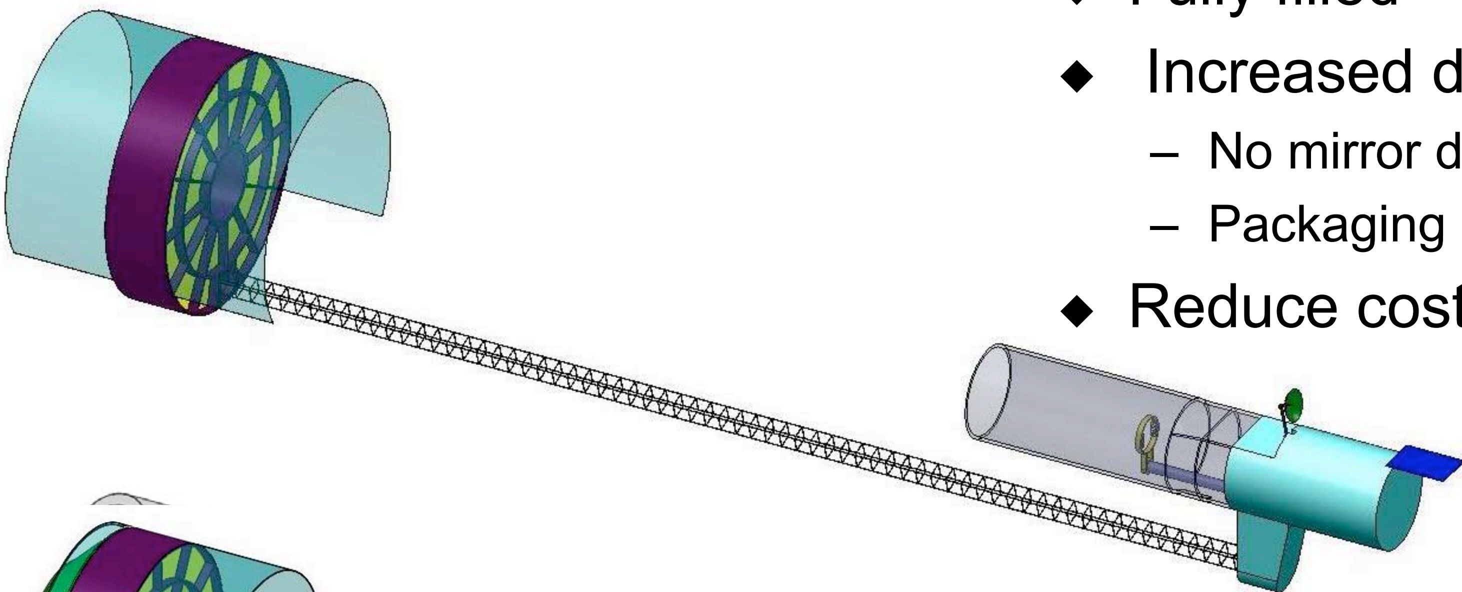
Ares V Stowed Configuration

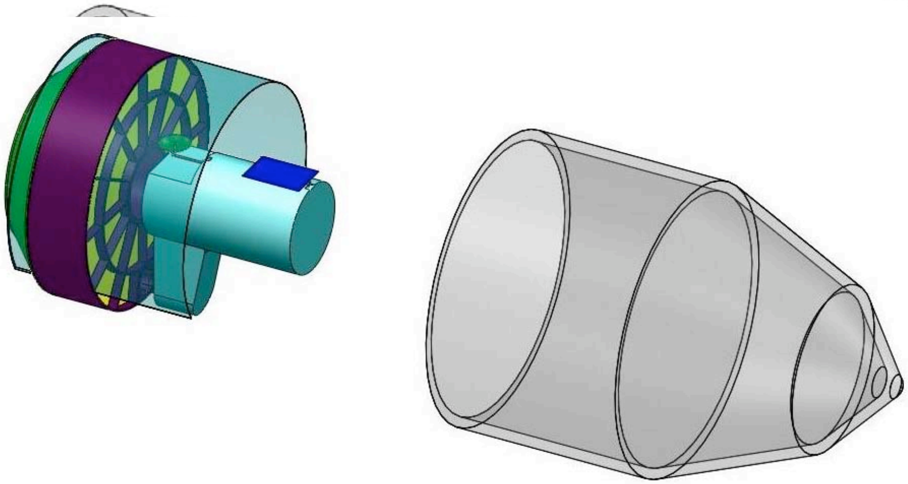
Dimensioned 16-m Deployed and Stowed



Wishing for a ~12.4-m Faring: Allows Monolithic Mirror

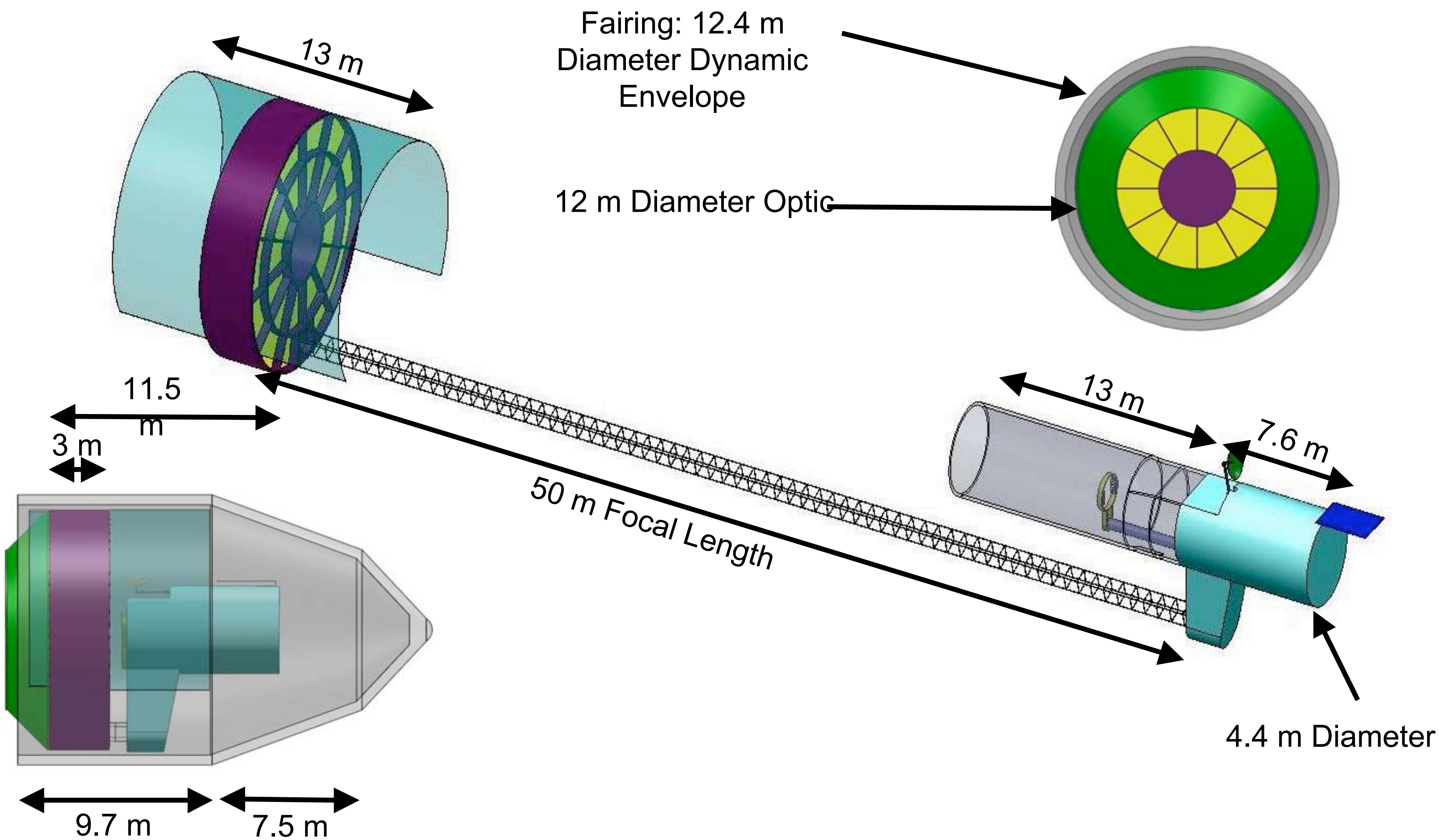
- Fully filled ~12 m optic
- Increased design freedom
  - No mirror deployment
  - Packaging
- Reduce cost and risk





Ares V Stowed Configuration

Dimensioned 12-m Deployed and Stowed



Ares V Considerations

- Large dynamic envelope (diameter and length)
- Gen-X is volume limited not mass limited
  - ~22 MT compared with ~60 MT capability to L2
  - Mass margin enables design freedom for optics and structure, supporting electronics and science instruments
- Mechanical and acoustic launch loads
  - Comparable to other launch vehicles, e.g., Delta 4H

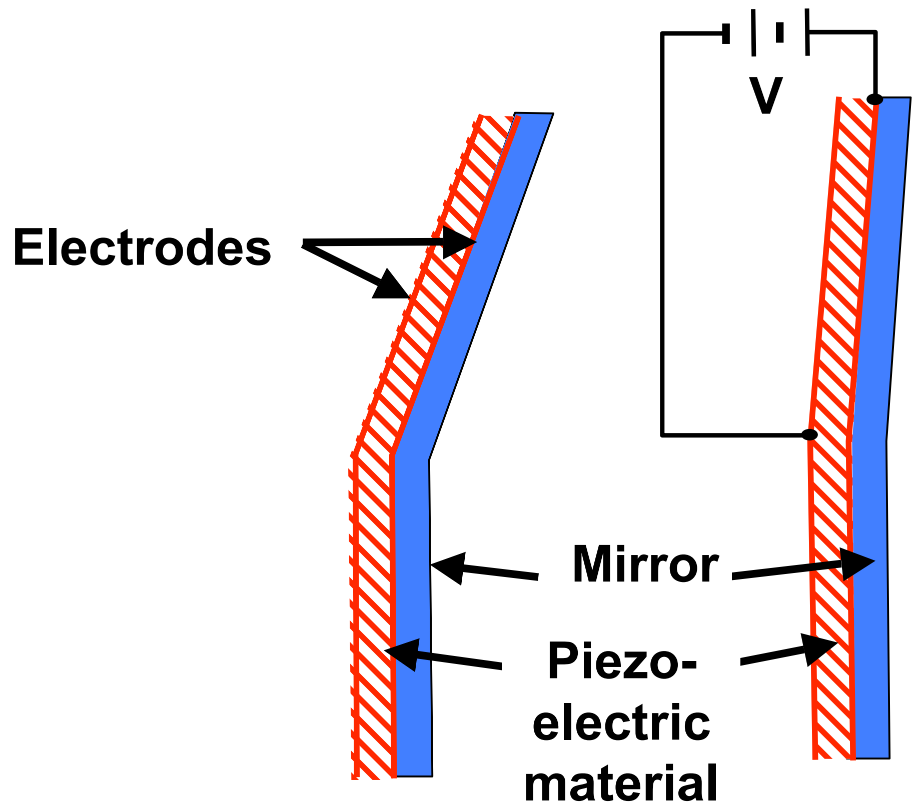
Ares V Applicability

	Gen-X Requirement	Ares V Capability	Applicability
Mass to Sun-Earth L2 (metric tons)	>22.3	59.4	✔
Shroud Inner Diameter (m)	>8.2	8.77	✔
Shroud Height (m)	>16.9	17.2	✔
Availability Date	2025+	~2020	✔

Technology Development: Optics are the Driver

Active Optics Mirror: Bimorph Piezoelectric Actuators

- No need for reaction structure
- Low power, weight
- Natural match to thin reflectors (0.2 mm)
- Mechanical actuators: hysteresis, backlash, lubricants
- Similar technology under development at synchrotrons
- R&D efforts underway at SAO



Preliminary Gen-X Technology Development Roadmap

System	Technology	Heritage	Present Capability	Requirement	TRL TG1	TG2	TG3	TG4	TG5
Mirror	Mirror Figure	XMM, *Con-X*	10^3Å over 0.2 m	40Å over 1 m	2	3	4	5	6
	Mirror Modules	XMM, *Con-X*	~100 shells aligned to ~3″	~200 shells aligned to 0.05″	2	3	4	5	6
	Mirror Deployment	JWST	Mechanism heritage	Alignment of modules to 0.05″	2	3	4	5	6
XMS	Multiplexing Pixel Array	*Suzaku*, *Con-X*	6x6 (Suzaku)	1800 x 1800	2	3	4	5	6
	Energy Resolution	*Suzaku*, *Con-X*	6eV at 5.9keV (Suzaku)	2 eV@6 keV	4	5	6		
Grating	Transmission Reflection	*Einstein* XMM, *Chandra*	~5000 lp mm^{-1}	~10^4 lp mm^{-1}	2-3	4-5	6		
WFI	Active Pixel Imager	JWST	Read noise: $10e^-$ @50Hz	$2e^-$ @ 1 MHz	2	3	4	5	6
			Size: 128x128	4000x4000	2-3	4	5	6	
			Depletion Depth: 15 μm	100 μm	2	3	4	5	6
			Vid. Processor: 36 parallel channels	1000 parallel channels	2	3	4	5	6

Preliminary Gen-X Technology Development Roadmap

System	Tech-nology	Heritage	Present Capability	Require-ment	TRL TG1	TRL TG2	TRL TG3	TRL TG4	TRL TG5
Mirror	Mirror Figure	XMM *Con-X*	10^3Å over 0.2 m	40Å over 1 m	**2**	**3**	**4**	**5**	**6**

Conclusions

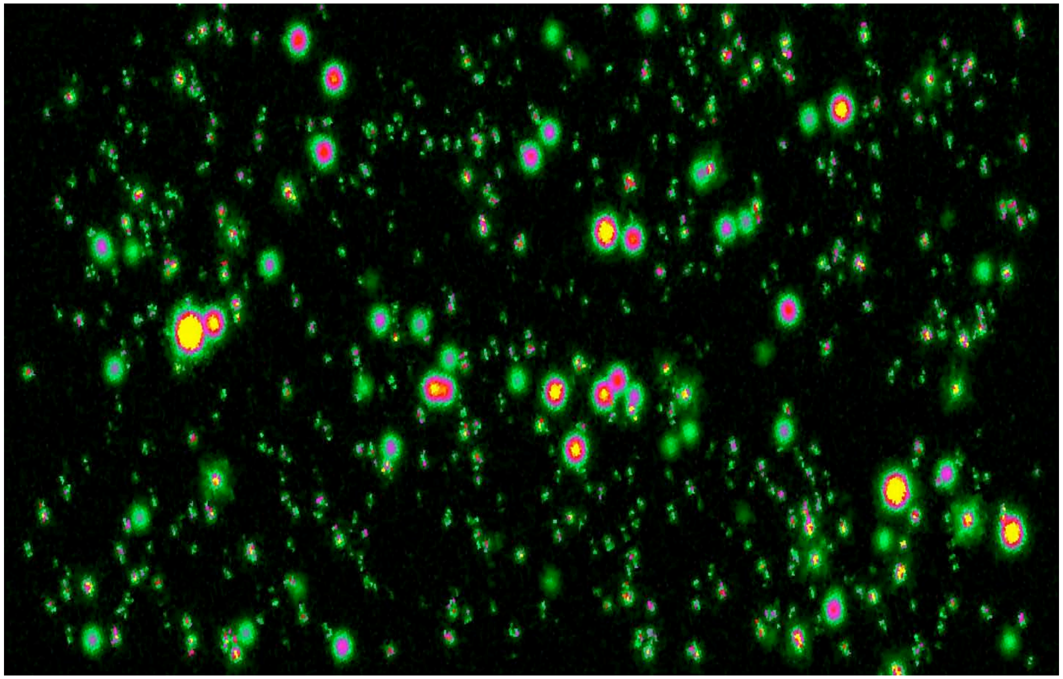
- Gen-X key science goals: observe the first black holes, stars and galaxies, and trace their evolution
- Large area: 50 m^2, high resolution: 0.1" requires innovative active approach to mirror figure control
- Study baseline:
  - 16 m-diameter deployable optic, Instruments on extendable boom,
  - 50 m^2 effective area, 60 m focal length
  - Ares V Launch to L2
- Study will produce Technology development plan with emphasis on optics for presentation to the Decadal Survey

- Ares V enables Gen-X
  - Streamlined and cost effective mission design and launch
  - 10m faring supports deployable optic, 12m would allow monolithic

Backup Charts

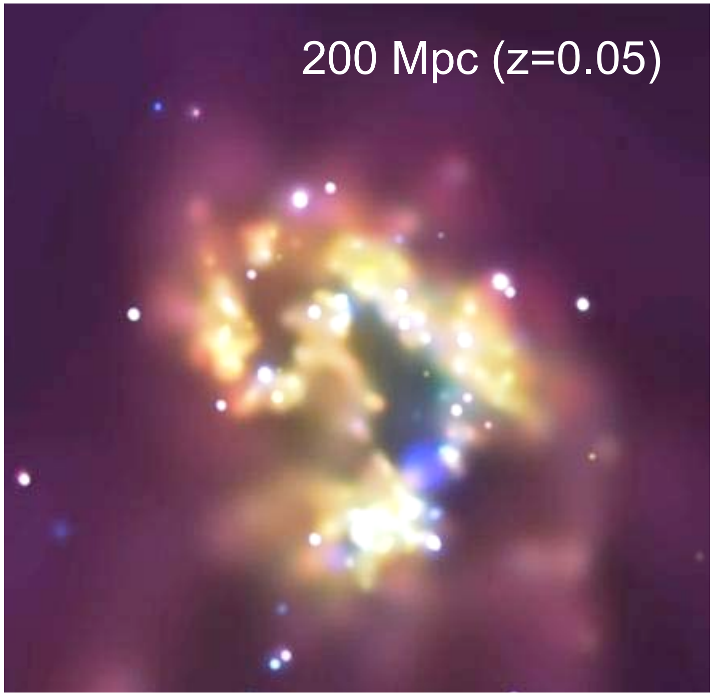
Studying Galaxy Component Evolution with z
Gen-X View of the Hubble Deep Field

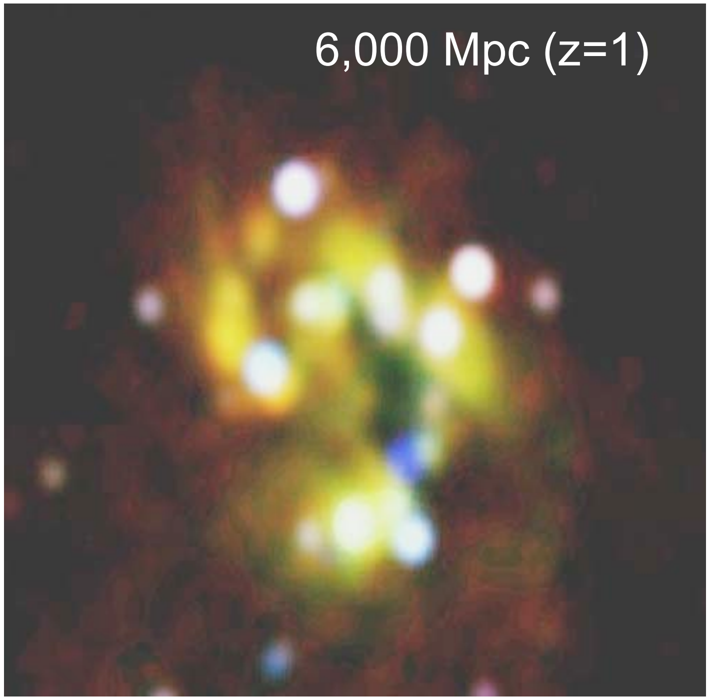
- z=1-3 galaxies show increased SFR and Lx; X-ray evolution
- For Hubble Deep Field, Chandra detects only 17 sources in 2 Ms
- Gen-X would detect most of the 3000 galaxies seen by HST
- ~800 galaxies at z~3 with >=400 counts in 1 Ms
- Spatially separate XRB from nuclear BH; spectrally separate hard XRB emission from hot gas to reveal true SFR



- Drives Gen-X Effective Area of 50 m^2, Angular Resolution of 0.1" and 0.1-10 KeV Energy Range

Gen-X View of Galaxy Evolution



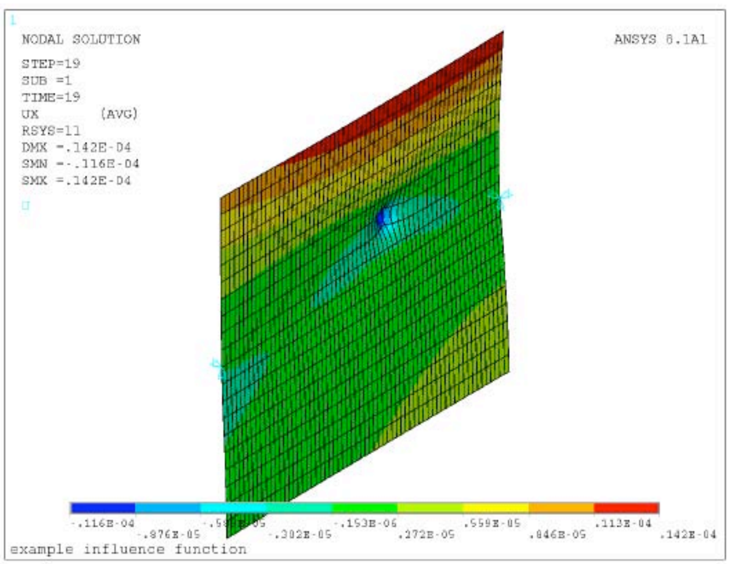


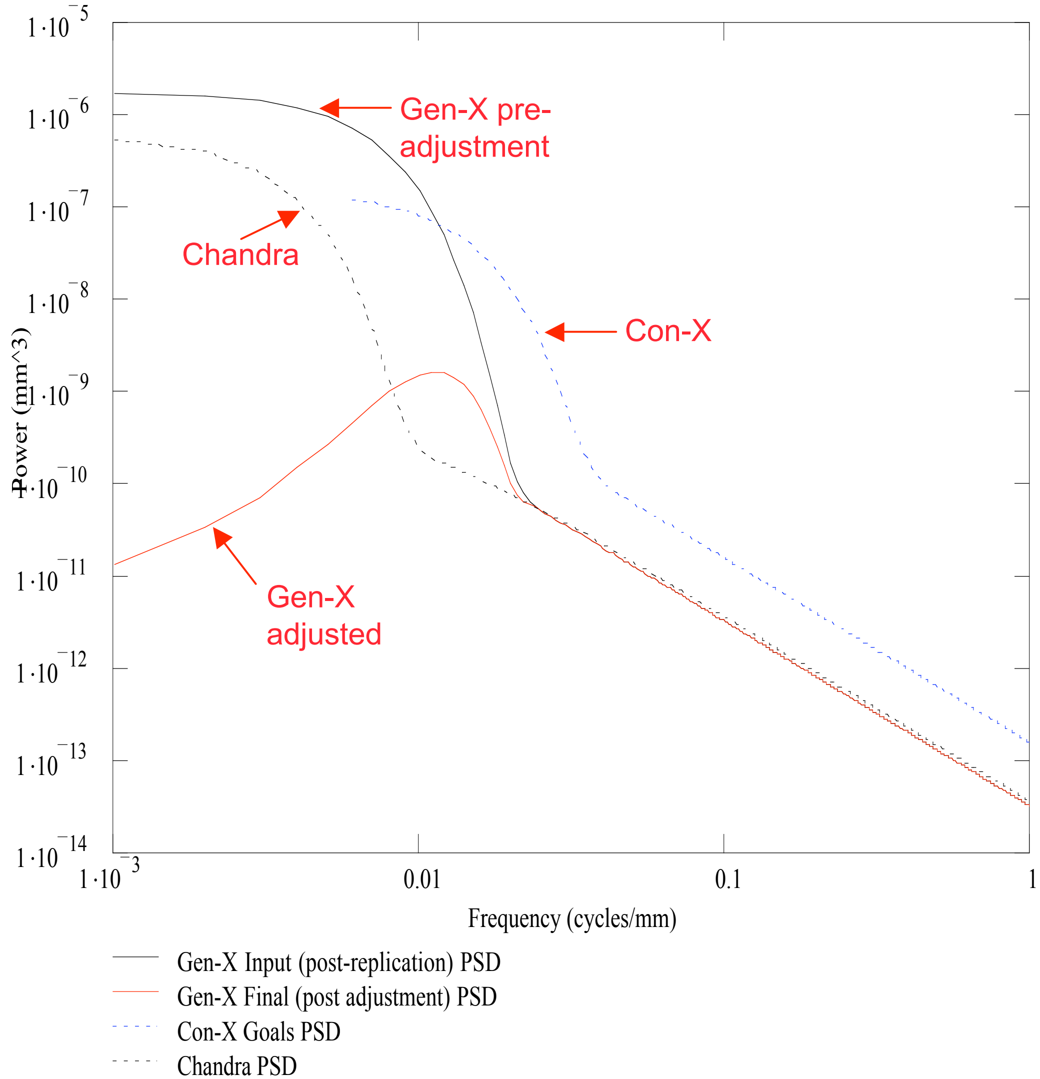
Simulated interacting galaxies to z=1

- Gen-X sufficiently resolves the dominant X-ray binaries to allow X-ray 'Population Synthesis' and study of galaxy evolution
- Study chemical evolution with SNR to 10 Mpc; high resolution spectra of Fe, Si and O drives requirement $E/\Delta E = 10^3 - 10^4$

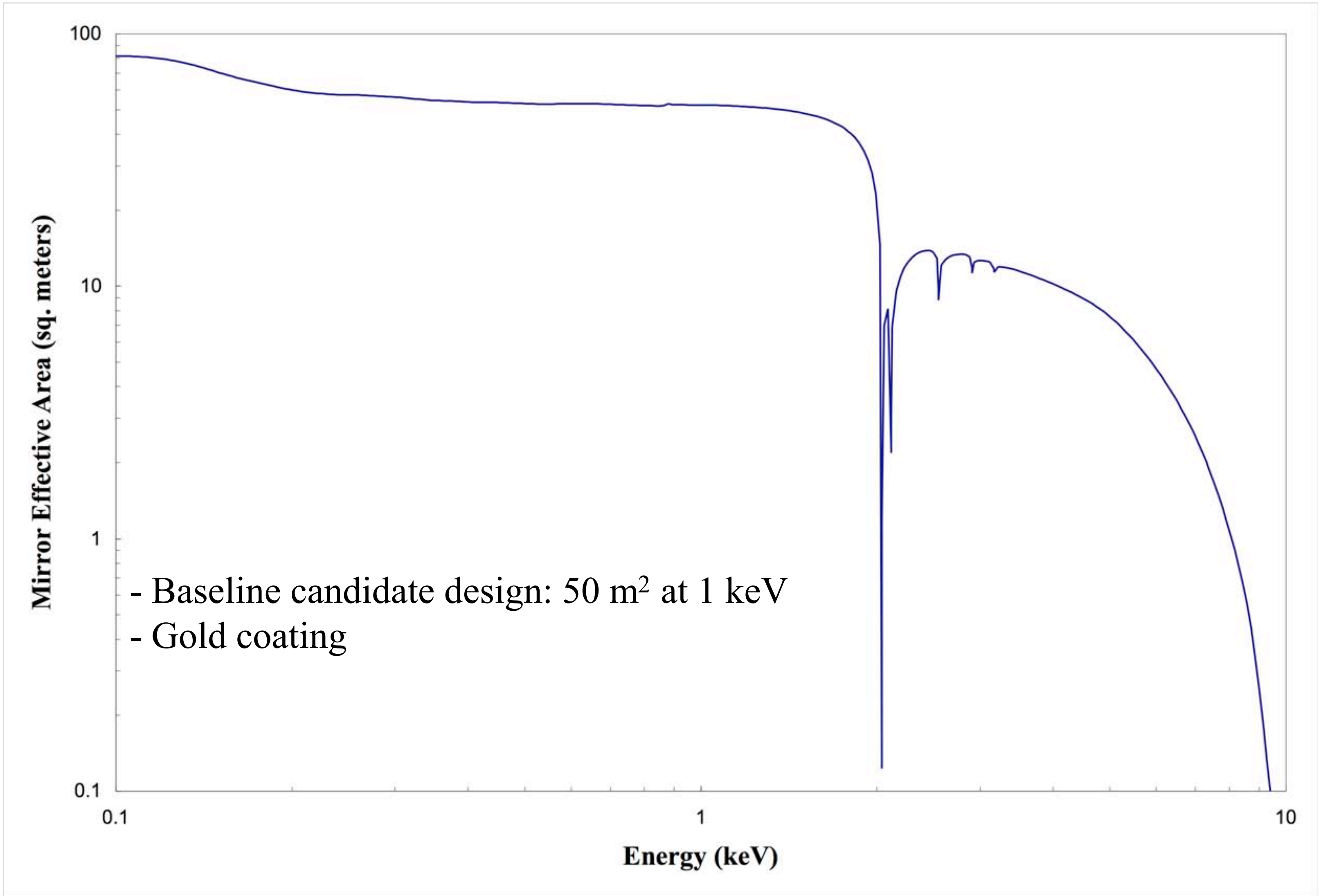
Controlling Mirror Figure

- Axial figure error PSDs for Gen-X, Con-X and Chandra
- Radial deformation in 40 μm piezo
- 2 cm piezos give axial figure correction of 0.025 mm^{-1}



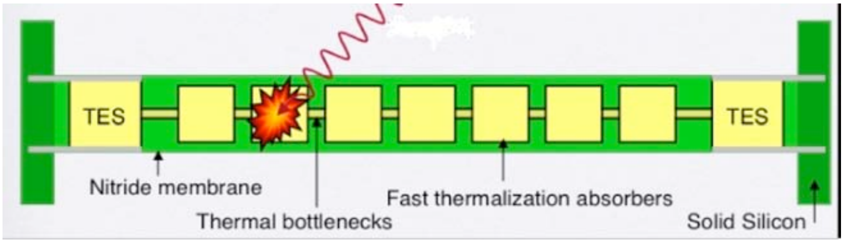


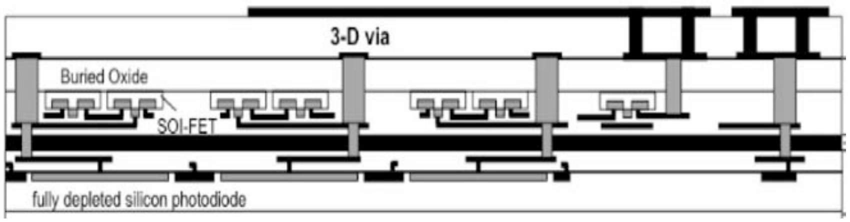
Mirror Effective Area



Study Focus: Technology Development Plan

- Telescope and Optics
  - Figure: on-orbit adjustment
  - Modules: alignment
  - Deployment
- Science Instruments
  - XMS: array pixel count, energy resolution
  - WFI: read noise, pixel size, dark current
  - XGS: ruled grating
- Spacecraft and Mission
  - Solar collector and thermal control system
  - Deployables: optical bench, sun shade
  - VM Study found s/c at TRL 4-6





➪ Optics are the major driver

Gen-X Mass Estimate

OPTICS Assembly			
Subsystem	Mass Estimate (kg)	Margin	Estimate + Margin (kg)
X-ray Mirror Assembly			
Glass	3900		
Structure	7800		
Mechanisms	300		
Inflatable Sunshields	180		
Thermal Control	140		
Optics Subtotal	12320		
Able Mast			
Mast including canister	400		
SPACECRAFT Components			
ACS	344		
Thermal Control	140		
Propulsion	70		
Power	324		
C&DH	308		
Communications	6		
Spacecraft Bus Subtotal	1192		
DETECTORS			
Subsystem	Mass Estimate (kg)	Margin	Estimate + Margin (kg)
X-ray Microcalorimeter	500		
Wide Field Imager	150		
Reflection Grating Assembly	150		
Rotation/Translation Mechanism	65		
Inflatable Sunshields	174		
Science Payload Subtotal	1039		
DETECTOR END BUS			
Structure	2214		
Total Mass	17165	30	22315
Ares V Payload to L2			59000

Mission Summary

Mission

Launch Date	2025-2035
Configuration	1-tel. f=60 m
Launch	Ares V
Orbit	Sun-Earth L2
Pointing	6 arcsec
Aspect	0.05 arcsec
Data Rate	~50 Gbytes/day
Comm.	DSN: Ka, X-band

Optics

EA	50 m^2 @ 1 keV
Angular Res.	0.1"
FOV	~5 arcmin

Science Instrument Requirements

Energy Range	0.1 - 10 keV
E/ ΔE	1000
Counting Rate	100 /s/pixel
Calibration	3% absolute
Background	0.004 cts/ks/$arcsec^2$
Time Res.	50 μs

Science Instruments

XMS	3x3 arcmin of FOV
	0.1 arcsec/pix
	E/ΔE~2eV @ 1 keV
WFI	Active pixel sensor
	Grating readout
RGS	E/ΔE >5000 E<1 keV